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PATENT SPECIFICATION

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COMPLETE SPECIFICATION

Improvements in or relating to Gas Turbine Installations

We, SULZER FRÈRES SOCIÉTÉ ANONYME, a Company organised under the Laws of Switzerland, of Winterthur, Switzerland, do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

This invention relates to gas turbine installations of the kind comprising a main turbo-compressor and a main turbine, the compressed working medium from the main turbo-compressor being fed through a recuperator in which heat is supplied thereto, in addition to combustion apparatus from which the products of combustion pass to the main turbine. The compressed medium which enters the combustion apparatus in such installations may be pure air, or air and combustible gas or mixture of gases, but for the sake of convenience it will be assumed herein to be air.

In a gas turbine installation of the above kind according to the present invention the working medium leaves the main turbine at a pressure above atmospheric pressure, flows through the recuperator so as to impart heat to the compressed air and is then further expanded in an auxiliary turbine which drives an auxiliary turbo-compressor.

The main turbine and turbo-compressor will be referred to as the main set while the auxiliary turbine and turbo-compressor will be referred to as the auxiliary set.

The auxiliary turbo-compressor preferably draws in air from the atmosphere and delivers it under pressure to the main turbo-compressor and in this case an intermediate cooler for the air may be interposed between the auxiliary turbo-compressor and the main turbo-compressor.

Again, means may be provided for varying at will the quantity of compressed air supplied to the combustion apparatus by controlling the speed of the auxiliary set and in this way the power output of the installation can be regulated.

If desired, the auxiliary set may be coupled to an auxiliary machine, for example a dynamo-electric machine, which can either absorb power from or give power to the auxiliary set for the purpose of controlling the speed of the auxiliary set as may be required for regulating the power output of the main set. Thus where the main set drives an electric generator and the auxiliary set drives an auxiliary dynamo-electric machine, the speed of this auxiliary dynamo-electric machine may be directly determined by the current output of the generator driven by the main set.

Again, means may be provided whereby the air compressed by the auxiliary turbo-compressor may be conveyed to the auxiliary turbine through an auxiliary combustion chamber so that the auxiliary set can be operated independently of the main set as a small gas turbine installation. With such an arrangement transmission apparatus including reduction gearing and a clutch may be provided whereby the auxiliary set can be coupled at will to the main set so that the auxiliary set can be employed to start the main set when the auxiliary set operates as an auxiliary gas turbine installation.

Further, valve apparatus may be provided in the pipe connecting the recuperator to the auxiliary turbine whereby this pipe can be connected at will either to an intermediate stage of the main turbine or to the atmosphere for the purpose of enabling a quick change in the speed of the auxiliary set to be obtained.

It is to be understood that each unit of the plant, that is to say each turbo-compressor, turbine, recuperator or combustion apparatus, may consist of several elements constituting the complete unit.

Since the total efficiency of a gas turbine installation of the kind referred to depends to a large extent on the individual efficiencies of the turbine and turbo-compressor, economical operation of the installation over a wide range of loads can only be obtained if both the main turbine and the main turbo-compressor work with a high degree of efficiency under different working conditions. The most obvious way of achieving this is to use a separate turbine

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for driving the main turbo-compressor and to operate this turbine at different speeds according to the load. This, however, is not altogether satisfactory.

Thus a multi-stage turbine can work efficiently only at a constant speed since the speed determines the pressure ratio and the latter in its turn controls the volume ratio. As, however, the turbine has an invariable cross-section for the flow of working medium, there is only one volume ratio at which all the stages work satisfactorily and consequently only one speed at which satisfactory operation can be obtained. If, however, the speed of a turbine is kept constant, the only possible way of regulating its output is to alter the whole pressure level throughout the machine, assuming that no throttling valves or "group" valves for permitting partial admission are arranged in front of the machine, since these cause additional losses. With the present invention it will be seen that the pressure ratio can remain the same and only the absolute pressures vary in a manner proportional to one another.

Two constructions according to the invention are illustrated diagrammatically by way of example in the accompanying drawings, in which

Figure 1 is a diagrammatic illustration of one form of installation according to the invention,

Figure 2 is a heat-entropy diagram of a gas turbine installation according to the invention, intermediate coolers being provided between the stages of the turbo-compressor, while intermediate heating is provided between the stages of the turbine, and

Figure 3 shows diagrammatically a modified form of installation according to the invention.

The installation diagrammatically illustrated in Figure 1 comprises a main turbo-compressor 4, and a main turbine 8 together constituting the main set and driving an electric generator 20, and an auxiliary turbo-compressor 2 and an auxiliary turbine 10 together constituting the auxiliary set.

Air or a combustible gas or gas mixture is drawn in by the auxiliary turbo-compressor 2 and delivered by a pipe 3 to the inlet end of the main turbo-compressor 4 which will normally be constructed as a cooled turbo-compressor. The air compressed by the main turbo-compressor 4 is delivered by a pipe 5 through a recuperator 6 in which this air is heated by the exhaust from the main turbine 8 and thence through a combustion chamber 7 in which combustion takes place and from which the gases pass to the inlet end of the main turbine 8. The main turbine is conveniently constructed as a turbine with a plurality of intermediate combustion stages in which additional heat is thus supplied to the gases.

The gases are not expanded in the main turbine to atmospheric pressure but are discharged through the pipe 9 at a pressure appreciably above atmospheric pressure and then flow through the recuperator 6 in which a large part of the heat is transmitted therefrom to the air flowing through the pipe 5. The gases thus flow from the recuperator 6 in a cooled state into the auxiliary turbine 10 in which these gases are expanded substantially to atmospheric pressure and discharged at 11.

The control of the plant thus far described can be effected in such a manner that the speed of the auxiliary set 2, 10 is determined in accordance with the load on the main set. Thus the initial pressure at which air is delivered through the pipe 3 to the main turbo-compressor 4 can be varied in accordance with the load, whereupon a corresponding variation takes place in the end pressure at which gas leaves the turbine 8 through the pipe 9, both which pressures normally in practice have approximately the same value. Thus the total pressure level in the main unit constituted by the turbo-compressor 4 and the turbine 8 can be varied in accordance with the load while this set can work at all times with practically constant efficiency. It is true that the efficiency of the auxiliary set constituted by the turbo-compressor 2 and the turbine 10 depends to some extent on its speed (that is to say on the load) but variations in the efficiency of this set are not excessive since, owing to the small pressure conditions thereof, it can operate with a comparatively small number of stages.

It will generally be found desirable to insert between the auxiliary turbo-compressor 2 and the main turbo-compressor 4 an intermediate cooler, as indicated at 13.

Further, in order to enable the speed of the auxiliary set to be changed as quickly as possible, piping and valves, as indicated at 15 and 16, may be provided whereby the inlet side of the turbine 10 can be connected to any desired intermediate stage of the main turbine 8 or can be connected to the atmosphere. Thus sudden changes can be effected in the pressure at which gases are supplied to the auxiliary turbine 10 and hence in the speed of this turbine.

If, as in the construction shown, a dynamo-electric machine 12 is driven by

the auxiliary set, this electric motor may be coupled electrically to the generator 20 driven by the main set in such a manner that the speed of the dynamo-electric machine 12 is determined by the speed of the generator 20, the dynamo-electric machine 12 acting either to reduce or increase the speed of the auxiliary set according to the speed of the generator 20. In this way it is possible to regulate the whole installation directly by variations occurring in the electric power requirements of the system fed by the generator 20. The centrifugal governor (not shown) of the main set which would normally be provided then acts merely as a speed-correcting member at least within the load range over which regulation can be effected by changes in the speed of the auxiliary turbine 10 alone.

If desired the auxiliary set may be utilised to start the main set. To this end the auxiliary set may be operated as an independent small gas turbine installation and means will then be provided for supplying heat, for example by means of a burner, to the working fluid before its admission into the auxiliary turbine 10. In certain conditions it may also be advisable to provide a pipe by which air can be passed from the auxiliary turbo-compressor 2 directly into the auxiliary turbine 10 through combustion apparatus, as indicated at 14.

It will be appreciated that means must in this case also be provided for enabling power to be transmitted from the auxiliary set to the main set and this may be done by any desired mechanical, hydraulic or magnetic coupling, for example a mechanical clutch, as indicated at 21, incorporated in transmission gearing connecting the two sets.

Alternatively in the arrangement in which a dynamo-electric machine 12 is coupled to the auxiliary set, it will be appreciated that this machine may be driven as a generator by the auxiliary set working as an auxiliary gas turbine installation, the current generated by the machine 12 then being transmitted through the conductors 50 and regulating apparatus 51 to the main generator 20 which then acts as a motor to start the main set.

The regulating apparatus 51 may serve to regulate the transmission of power between the dynamo-electric machine 12 and the generator 20 in both directions.

The operation of the machine as shown by the entropy diagram in Figure 2 is as follows. The line 22—23 represents the period of compression in the auxiliary compressor 2, 23—24 represents intermediate cooling, 24—25 represents the period of compression in the first stage or set of stages in the main turbo-compressor 4, 25—26 the first intermediate cooling in the main turbo-compressor 4, 26—27 the period of compression in the next stage of the main turbo-compressor 4, 27—28 the next intermediate cooling in the main turbo-compressor 4 and 28—29 the period of compression in the third stage or set of stages in the main turbo-compressor 4. The line 29—30 represents the heating imparted to the air in the recuperator 6 and 30—31 the heating imparted to the air in the combustion apparatus 7. 31—32 represents the period of expansion in the first stage or group of stages of the main turbine 8, 32—33 represents the first period of interstage heating in the main turbine 8, 33—34 the expansion in the next stage, 34—35 the second interstage heating, 35—36 the expansion in the third stage, 36—37 the next interstage heating and 37—38 the expansion in the final stage of the main turbine 8. At the point 38 the pressure of the gases is still considerably above atmospheric pressure. 38—39 represents the cooling of the gases in the recuperator 6, and 39—40 the period of expansion of the gases in the auxiliary turbine which drives the auxiliary turbo-compressor 2.

It will be seen from the entropy diagram that a change in the heat variation represented by the line 22—23 and that represented by the line 39—40 as indicated in dotted lines will, with a suitable adjustment of the cooling between the compressor 2 and the compressor 4, result in a substantially horizontal shifting of the whole remainder of the diagram so that all the heat gradients still remain practically constant and the power of the plant is altered merely by the whole process taking place over a different range of specific volumes.

In the alternative construction diagrammatically shown in Figure 3 the apparatus comprises a main turbo-compressor 4 connected to a main turbine 8 driving an electric generator 20, and an auxiliary turbo-compressor 2 supplying air through a pipe 3 to the main turbo-compressor 4 and driven by an auxiliary turbine 10 connected to a dynamo-electric machine 12 and coupled through conductors 50 and a regulating device 51 to the generator 20, as in the construction shown in Figure 1. In the construction shown in Figure 3, however, only part of the total quantity of gas passing through the main turbine 8 is caused to flow at a pressure higher than atmospheric pressure to the auxiliary turbine 10 through the recuperator 6^1 and is then finally

expanded in the auxiliary turbine 10, the remainder of the gas being expanded to its final pressure in the main turbine 8 and then passed through a recuperator 6^{11} in which it is cooled by giving up heat to air delivered by the main turbo-compressor 4 through the combustion apparatus 7 to the main turbine 8.

The operation of the installation shown in Figure 3 is thus as follows. The working medium is compressed in the auxiliary compressor 2 and passes therefrom through the pipe 3 to the main compressor 4 which, as before, may have interstage cooling. The air delivered by the main compressor 4 flows through two separate passages, one part of the air flowing through the recuperator 6^{11} which is heated by the working medium leaving the final stage of the main compressor, while the other part passes through the recuperator 6^1 in which it is heated by the working medium flowing from an intermediate stage in the main turbine 8 to the auxiliary turbine 10. The two air passages both lead to the combustion apparatus 7. In this construction also the main turbine 8 has interstage heating.

Having now particularly described and ascertained the nature of our said invention and in what manner the same is to be performed, we declare that what we claim is:—

1. A gas turbine installation of the kind referred to, in which the gases leave the main turbine at a pressure above atmospheric pressure, flow through the recuperator so as to impart heat to the compressed air and are then further expanded in an auxiliary turbine which drives an auxiliary turbo-compressor.

2. A gas turbine installation as claimed in Claim 1, in which the auxiliary turbo-compressor draws in air from the atmosphere and delivers it under pressure to the main turbo-compressor.

3. A gas turbine installation as claimed in Claim 2, in which at least one intermediate cooler for the air is interposed between the auxiliary turbo-compressor and the main turbo-compressor.

4. A gas turbine installation as claimed in Claim 1 or Claim 2 or Claim 3, in which the quantity of compressed air supplied to the combustion apparatus can be varied at will by controlling the speed of the auxiliary turbine and turbo-compressor for the purpose of regulating the power output of the installation.

5. A gas turbine installation as claimed in any one of the preceding claims, in which the auxiliary turbine and turbo-compressor are coupled to an auxiliary machine, for example a dynamo-electric machine, which can either absorb power from or give power to the auxiliary turbine and turbo-compressor for the purpose of controlling the speed of the auxiliary turbine and turbo-compressor and regulating the operation of the installation.

6. A gas turbine installation as claimed in Claim 5, in which the main turbine drives an electric generator and the auxiliary machine is in the form of a dynamo-electric machine so electrically coupled to the generator that its speed is determined directly in accordance with the power given out by the generator.

7. A gas turbine installation as claimed in Claim 1, in which an auxiliary combustion chamber is provided through which the air delivered by the auxiliary turbo-compressor can be supplied direct to the auxiliary turbine for the purpose of enabling the auxiliary turbo-compressor and turbine to be run independently when desired as a gas turbine installation.

8. A gas turbine installation as claimed in Claim 7, in which the auxiliary turbine and turbo-compressor can be coupled at will to the main turbo-compressor and turbine through reduction gearing and a clutch whereby the main gas turbine plant can be started by the auxiliary turbine and turbo-compressor acting as a gas turbine installation.

9. A gas turbine installation as claimed in Claim 1, in which valve apparatus is provided in the pipe connecting the recuperator to the auxiliary turbine whereby this pipe can be connected at will either to an intermediate stage of the main turbine or to the atmosphere for the purpose of enabling a quick change in the speed of the auxiliary turbine and turbo-compressor to be obtained.

10. A gas turbine installation as claimed in any one of the preceding claims, in which only a part of the products of combustion are taken from the main turbine at a pressure above atmospheric pressure, passed through the recuperator and are then expanded in the auxiliary turbine while the remaining part of these gases is expanded in the main turbine approximately to atmospheric pressure and then passed through a second recuperator.

11. A gas turbine installation as claimed in any one of the preceding claims, in which any one or more of the units of which the installation consists is in the form of a series of elements or stages together constituting the unit.

12. A gas turbine installation as claimed in any one of the preceding claims, in which means are provided

whereby power can be transmitted from the auxiliary turbine and turbo-compressor to the main turbine and turbo-compressor for the purpose of enabling the main turbine and turbo-compressor to be started up by power supplied thereto from the auxiliary turbine and turbo-compressor operating as an independent gas turbine installation.

13. A gas turbine installation as claimed in Claim 7, in which during starting of the main turbine and turbo-compressor the dynamo-electric machine coupled to the auxiliary turbine and turbo-compressor acts as a generator the output of which is supplied to a main generator coupled to the main turbine and turbo-compressor.

14. The complete gas turbine installation substantially as described with reference to and diagrammatically illustrated in Figure 1 or in Figure 3 of the accompanying drawings.

Dated this 26th day of May, 1939.

KILBURN & STRODE,
Agents for the Applicants.

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[This Drawing is a reproduction of the Original on a reduced scale.]

Fig.1.

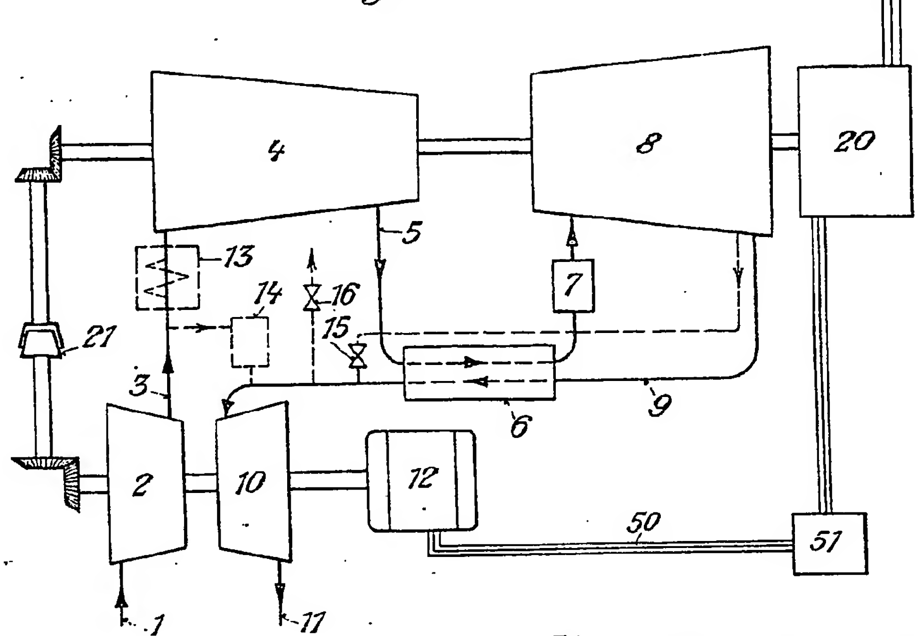

Fig.2.

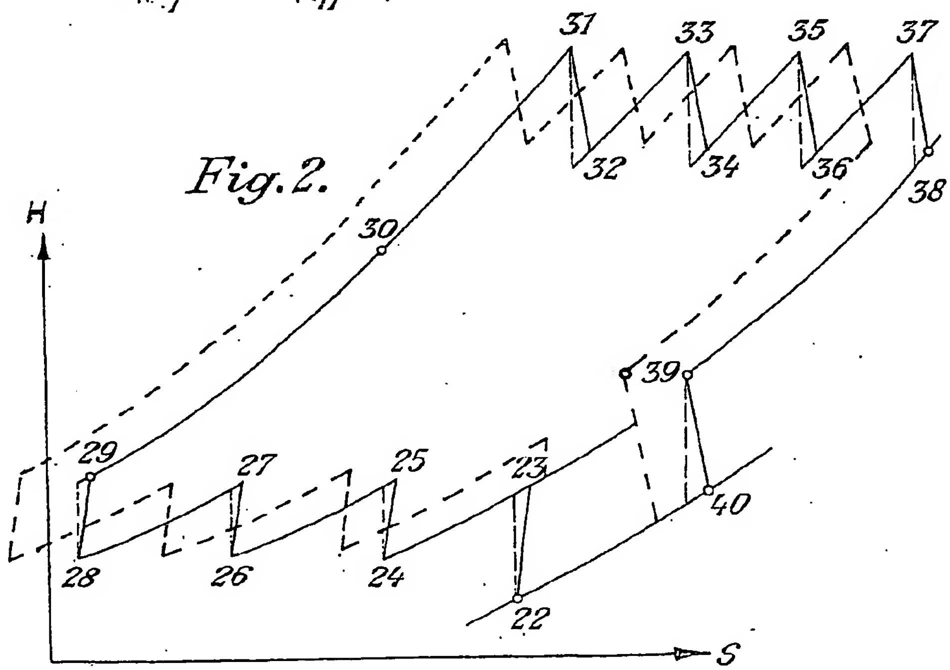

Fig. 3.

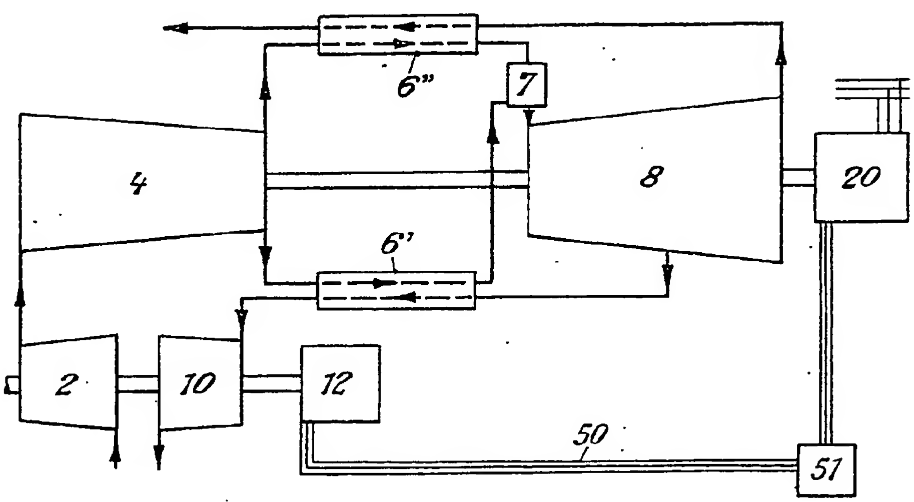

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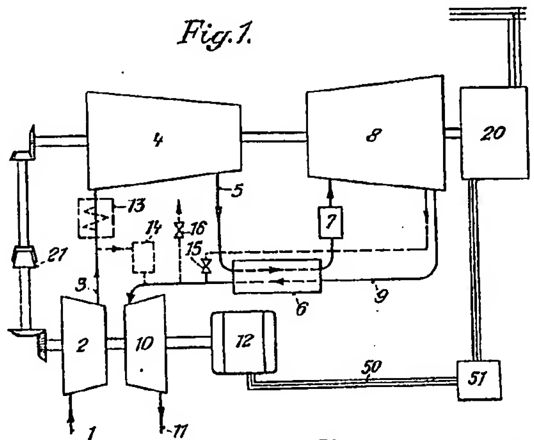
Fig.1.



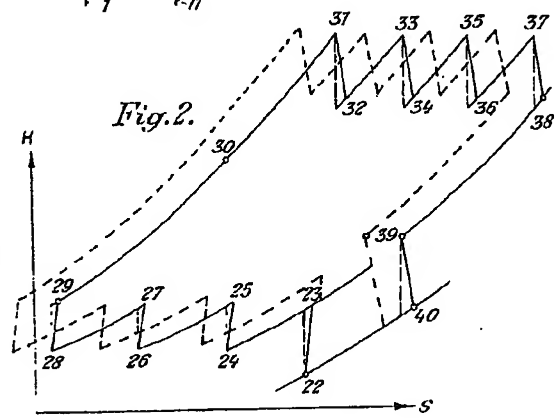
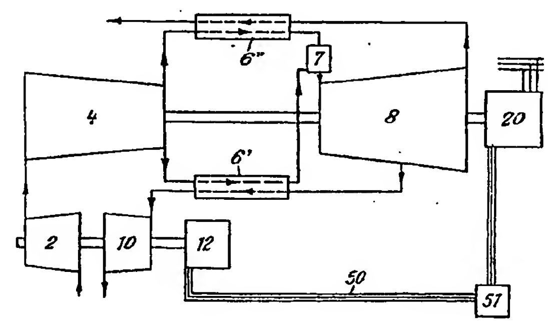


Fig.2.

Fig.3.



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